ULTRA WIDEBAND RADAR TARGETS DISCRIMINATION USING FREQUENCY DOMAIN E-PULSE METHOD

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Abstract: *A frequency domain approach to the E-pulse radar target discrimination technique is introduced. This approach allows the interpretation of E-pulse convolution via the E-pulse spectrum. The addition of extra zeroes to E-pulse structure has been suggested and its influence on the increasing of discrimination accuracy has been proved. The results of discrimination scheme digital simulation by using the characteristic E-pulse parameters for known targets are presented.*

I. INTRODUCTION

Ultra wideband radar proposes the use of sharp pulses with duration about units of nanoseconds. These pulses excite electromagnetic oscillations in a target with frequencies defined by geometric range and form of the target. According to the Baum's singularity expansion method (SEM) [1] scattered target response can be represented as a sum of damped oscillations:

$$y(t) = x(t) + w(t) = \sum_{k=1}^{K} A_k e^{-\sigma_k t} \cos\left(2\pi f_k t + \varphi_k\right) + w(t), \tag{1}$$

where $\sigma_k + j2\pi f_k$ is the k-th natural complex frequency; A_k и φ_k are the amplitude and phase of k-th target mode; $w(t)$ is additive Gaussian noise, K is the number of natural modes containing in the response. It's important to notice that natural complex frequencies are aspect independent.

Identification methods using in the ultra wideband radar can be divided into parametrical and non-parametrical one. Parametric methods consist in the estimation of the target natural frequencies in the measured response. Determined parameters can be compared to the known parameters of the targets included in the database and identification decision can be made relaying on it. Such known methods as Prony's method, pencil-of-function method, ESPRIT [2], are parametrical.

Another way to the ultra wideband target discrimination is the *E*-pulse method [3]. This method offers to fit special signal (*E*-pulse) to the target response so the convolution of the response and the signal is minimal (or equal to zero) after the moment determined by the signal parameters.

There are several ways to *E*-pulse synthesis. Time domain *E*-pulse synthesis uses low-noised impulse response and natural frequency value estimated by any parametric method. Known methods approximate the time-domain response or its spectrum by *E*-pulse, which can be synthesized by using known algorithm. This paper shows frequency domain *E*-pulse synthesis method.

Radar target discrimination scheme using *E*-pulse technique is the following. There are discrimination signal database for every radar target class. The measured response is sent to the input of discrimination system, which convolves it with every *E*-pulses stored in the database. The minimal parameter of convolution will correspond to the determined target.

The paper is organized as follows. In section II frequency domain *E*-pulse synthesis theory is represented. The results of digital simulation using scaled aircraft model responses present in section III. Finally, some remarks are considered in conclusion.

II. FREQUENCY DOMAIN E-PULSE SYNTHESIS

E-pulse technique proposes the forming of a finite discriminating signal $e(t)$ for the target response $x(t)$:

$$e(t) = \sum_{n=0}^{N} e_n h\left(t - nT_h\right) = \sum_{n=0}^{N} e_n \delta\left(t - nT_h\right) * h\left(t\right), \tag{2}$$

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where e_n is the amplitude of the *n*-th elementary impulse, T_h is the duration of the elementary impulse, *N* is the number of elementary impulses containing in the signal $e(t)$, $h(t)$ is the waveform of the elementary impulse: $h(t) = 0$, for $t < 0$ and $t > T_h$.

E-pulse parameters defining its discriminating features are the amplitudes of its elementary impulses e_n and the waveform $h(t)$. *E*-pulse parameters fitting scheme aim is the minimization (zeroing ideally) the convolution of the *E*-pulse $e(t)$ and the target response $x(t)$ in the time $t > T_e$:

$$c(t > T_e) \equiv 0, \quad c(t) = e(t) * x(t)\,. \tag{3}$$

Frequency domain *E*-pulse synthesis is based on the singularity expansion method. Let assign target natural mode complex value $\{\sigma_k + j2\pi f_k\}$ to be known and represented as poles $\{s_k\}$. Discretization of a signal maps *s*-plane poles onto complex *z*-plane $\{z_k\}$, so z-transform of the target response can be written as:

$$\widetilde{X}(z) = \prod_{j=1}^{M}(z - z_{0j}) \Big/ \prod_{i=1}^{N}(z - z_i) = \frac{L(z)}{P(z)}, \tag{4}$$

where z_i describes poles on *z*-plane, z_{0j} describes zeroes on *z*-plane, *N* and *M* are the number of the poles and the zeroes correspondingly.

Carrying out expression (3) the signal $c[n]$ must be finite, so its *z*-transform must be free from poles. On the other hand the *E*-pulse itself is the finite waveform and its *z*-transform $\widetilde{E}(z)$ contains no poles.

$$\widetilde{C}(z) = \widetilde{X}(z) \cdot \widetilde{E}(z) = \frac{L(z) \cdot E(z)}{P(z)} = C(z), \tag{5}$$

where $\widetilde{X}(z)$, $\widetilde{E}(z)$, $\widetilde{C}(z)$ are *z*-transforms of the target response, the *E*-pulse, fitted to the response, and their convolution correspondingly, and $L(z)$, $E(z)$, $P(z)$, $C(z)$ are *z*-power polynomials.

It's obviously that expression (5) requires *E*-pulse to meet the condition:

$$E(z) = P(z) \cdot D(z)\,, \tag{6}$$

where polynomial $P(z)$ coincides with the denominator of *z*-transform $\widetilde{X}(z)$, and $D(z)$ is some *z*-power polynomial. Thus the zeroes of $\widetilde{E}(z)$ should be placed in the same point of the complex plane where the poles of the target response $\widetilde{X}(z)$ lie. However in addition to them *E*-pulse can also consist some extra zeroes, described by the polynomial $D(z)$. The quality of the discrimination algorithm can be improved by optimal allocation of these zeroes.

Inverse *z*-transform of the polynomial $P(z)$ represents the minimal duration basic *E*-pulse $e_{base}[n]$. But this *E*-pulse can find practical application if discriminated targets poles lies far from each other only. In the case of close target poles allocation discriminating possibilities of this *E*-pulse is low, so extra zeroes addition is required. Extra zeroes addition increase *E*-pulse duration and its energy. It allows increasing information parameter value for the *E*-pulse convolution with foreign target response.

E-pulse extra zeroes can be placed at will, but the form (2) demands its allocation providing the absence of the each delta-function convolution product covering:

$$e_0[n] = \sum_{n=0}^{N} e_n \delta[t - n\Delta]\,, \tag{7}$$

where $e_0[n]$ is an extended *E*-pulse, shown in Fig. 1, Δ is the duration of elementary impulse $h[n]$; e_n are samples amplitudes. Extended *E*-pulse $e_0[n]$ consists of the same number of meaning samples, as minimal duration *E*-pulse does, but discrete numbers are divisible by Δ.

We have solved the mathematical problem of extra zeroes allocation providing form (7). This problem solving can be found as the fundamental solution of equitation set. According to it $(\Delta - 1)n_p$ (n_p is the number of the necessary zeroes) extra zeroes should be placed on *z*-plane. In this case *z*-transform of $e_0[n]$ has Δn_p zeroes, lying symmetrically about rays, traced from the point of origin and dividing the unit disk symmetrically into Δ equal sectors.

Other offered method parameter is elementary pulse waveform $h[n]$. Elementary pulse represents the sharp pulse of one or several samples duration. Choosing elementary pulse waveform it's important to consider its duration Δ to be the parameter of the structure (7). Practically we propose to choose $h[n]$ in order to make noise reduce as more as possible.

Thus above described frequency domain theory allows to synthesize *E*-pulse by the known radar target natural modes.

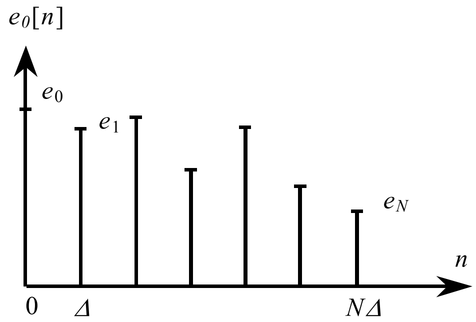

Fig. 1. Extended *E*-pulse e_0[n]

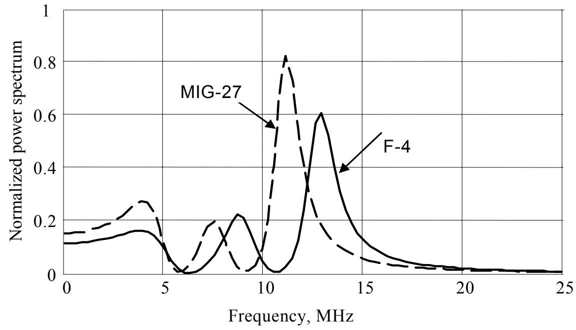

Fig. 2. Power spectrum of aircraft models

III. Discrimination of Radar Targets

Numerical estimation of E-pulse discrimination was accomplished by characteristic parameter Ψ [4]:

$$\Psi = \int_{T_e}^{+\infty} c^2(t)dt \bigg/ \int_0^{T_e} c^2(t)dt. \qquad (8)$$

Parameter Ψ can be measured in times or in decibels. The discrimination condition is the characteristic parameter minimum. There are two directions to make discrimination possibilities better. The former is characteristic parameter increasing for the *E*-pulse convolution with the foreign target response. The latter is the reduction of the parameter while *E*-pulse convolution with noised original target response comes.

Target responses power spectrums are represented in Fig. 2. It's seen three clearly marked natural modes, but the lower-frequency components of each spectrum are located close to each other while high frequency ones are different greatly.

E-pulse was synthesized for F-4 aircraft model. Elementary pulse waveform was taken as rectangle window [3], so targets poles lie in low frequency z-plane area. *E*-pulse elementary pulse duration equal to 7 samples was experimentally defined to get the best discriminating possibility. In that case the duration of the *E*-pulse created for the model containing 3 pairs of poles is equal 49 samples. Sampling frequency of target response was let as 300 MHz. Thus the *E*-pulse duration is 163,3 nanoseconds, and its component pulses duration is 23,3 nanoseconds. This *E*-pulse is shown in Fig. 3. As a test for (3) we've found the E-pulse convolution with F-4 and Mig-27 aircraft models responses. The results are presented at Fig. 4.

The convolution of F-4 model response and the *E*-pulse is equal to zero for the time grater then *E*-pulse duration. The characteristic parameter value is zero in that case, so we can consider this response to be exactly original target response.

The convolution of *E*-pulse synthesized of F-4 model and Mig-27 model response leads to the different result. Thus convolution for time greater then *E*-pulse duration isn't equal to zero so the characteristic parameter value differs from zero.

The *E*-pulse convolution with noised responses was always different from zero in the late time period. The instance of convolution with F-4 aircraft model response with SNR equal to 15 dB is given in Fig. 5. The late-time convolution value can be remarked different from zero. The characteristic parameter is nonzero too.

We have research the dependences the characteristic parameter from SNR for the above-mentioned aircraft models, and their plots are shown in Fig. 6. Fig. 6 shows, that characteristic parameters difference starts increasing for SNR equal to 15 dB and greater, it means that the algorithm will work properly. But for SNR less then 10 dB the graphs are asymptotic approaching to each other, so target discrimination becomes unavailable using this algorithm.

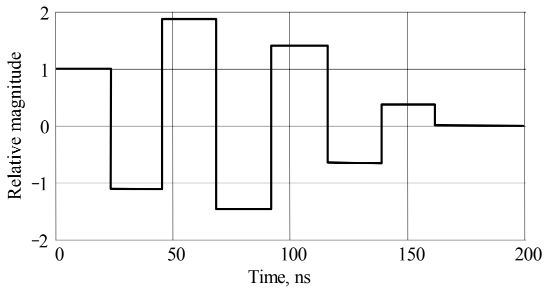

Fig. 3. *E*-pulse synthesized for F-14 model response suppression

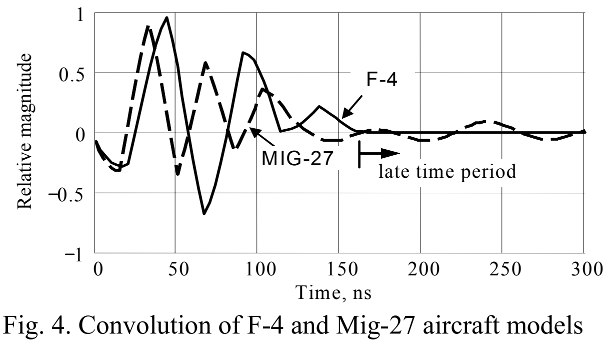

Fig. 4. Convolution of F-4 and Mig-27 aircraft models responses and E-pulse synthesized for the F-4

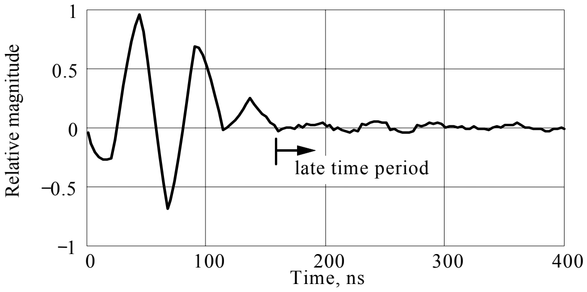

Fig. 5. The convolution of E-pulse synthesized for F-4 model and F-4 model response with SNR 20 dB

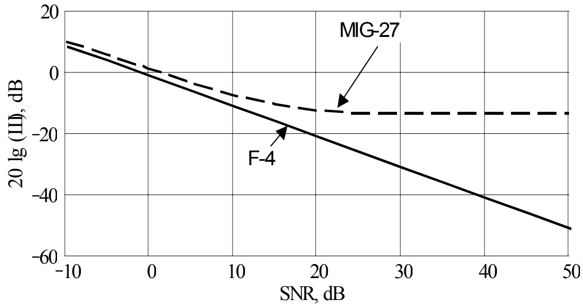

Fig. 6. The characteristic parameter dependence from SNR

IV. Conclusions

Frequency domain *E*-pulse synthesis is successfully used for the resonant model of ultra wideband radar targets. Based on the known target poles the discriminating signal that allows carrying out radar target identification can be synthesized. At that *E*-pulse zeroes should be placed in the point of z-plane where target response poles lie. The method leading to improve the discrimination possibilities by addition extra zeroes to *E*-pulse structure was proposed in the paper.

For instance, *E*-pulse synthesis was realized for the aircraft model which poles are known. Using *E*-pulse characteristic parameter digital simulation of the original and foreign target responses processing was done. Experimental results obtained using aircraft models have demonstrated the validity of radar target discrimination based on offered scheme.

References

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